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FRICTION STIR FORMING METHOD
[Masatsu kakuhan seikei hoho]

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[Claims] /2*

[Claim 1] A friction stir forming method constituted by:

causing relative movement between a friction heat-generating stirring means and a first object by abutting the friction heat-generating stirring means against the first object, with the first object and a second object in a state of contact, and

causing plastic flow in a non-melted state by introducing the friction heat-generating stirring means into the first object, generating friction heat between the first object and the friction heat-generating stirring means, and stirring a material constituting the first object in a heated state,

transferring a convexo-concave state formed on the second object by the plastic flow in this state.

[Claim 2] A friction stir forming method constituted by:

causing relative movement between a friction heat-generating stirring means and a first object by abutting the friction heat-generating stirring means against the first object, with the first object and a second object in a state of contact, and

causing plastic flow in a non-melted state by pouring the friction heat-generating stirring means into the first object, generating friction heat between the first object and the friction heat-generating stirring means, and stirring a material constituting the first object in a heated state,

* Claim and paragraph numbers correspond to those in the foreign text.

using the plastic flow to mechanically join the first and second objects.

[Claim 3] The friction stir forming method according to Claims 1 or 2, wherein:

the friction heat-generating stirring means is a rotation-drivably provided rotating tool to a tip of which is formed a workpiece contact face, and

friction heat is generated between the workpiece contact face and the first object.

[Claim 4] The friction stir forming method according Claim 1, wherein:

the convexo-concave state of the second object is a forming mold formed on the second object.

[Claim 5] The friction stir forming method according Claim 2, wherein:

materials constituting the first object and the second object differ.

[Claim 6] The friction stir forming method according Claim 5, wherein:

the material of the first object is a material with aluminum as a raw material, and the material of the second object is a material with iron as a raw material.

[Claim 7] The friction stir forming method according to Claim 2, constituted such that:

bumps and recesses are formed in a material of the second object, and the first and second objects are mechanically joined by pouring the material constituting the first object into those bumps and recesses.

[Detailed Description of the Invention]

[0001]

[Industrial Field of Application] The present invention relates to a friction stir forming method which allows formation without melting a metal material by using friction heat generated by rubbing two objects together.

[0002]

[Prior Art] Conventionally, the only method for transferring any convexo-concave shape onto metal was either to form a mold corresponding to the convexo-concave shape and cast it, or to cut it using machining.

[0003]

[Problem to be Solved by the Invention] In the case of casting, the need for melting a metal material required not only significant plant facilities, but also had the drawback of the mechanical nature thereof changing, and the machining had the inconvenience of requiring a great deal of time and skill.

[0004] In view of the above circumstances, the present invention has as an object to provide a friction stir forming method which

allows formation in a short time without melting materials and without requiring extensive skills.

[Means for Solving the Problem] The invention of the first claim is constituted by causing relative movement between a friction heat-generating stirring means (2) and a first object (6) by abutting the friction heat-generating stirring means against the first object, with the first object and a second object (5) in a state of contact, and causing plastic flow in a non-melted state by introducing the friction heat-generating stirring means into the first object, generating friction heat between the first object and the friction heat-generating stirring means, and stirring a material constituting the first object in a heated state, thus transferring a convexo-concave state formed on the second object by the plastic flow in this state.

[0005] The invention of the second claim is constituted by causing relative movement between a friction heat-generating stirring means (2) and a first object (6) by abutting the friction heat-generating stirring means against the first object, with the first object and a second object (7) in a state of contact, and causing plastic flow in a non-melted state by introducing the friction heat-generating stirring means into the first object, generating friction heat between the first object and the friction heat-generating stirring means, and stirring a material constituting the first object

in a heated state, thus using the plastic flow to mechanically join the first and second objects.

[0006] The invention of the third claim is constituted by the friction stir forming method according to Claims 1 or 2, wherein the friction heat-generating stirring means is a rotation-drivably provided rotating tool (2) to a tip of which is formed a workpiece contact face, and friction heat is generated between the workpiece contact face and the first object.

[0007] The invention of Claim 4 is constituted such that the convexo-concave state of the second object is a forming mold (5a) formed on the second object.

[0008] The invention of the fifth claim is constituted by the friction stir forming method according Claim 2, wherein materials constituting the first object and the second object differ.

[0009] The invention of the sixth claim is constituted by the friction stir forming method according Claim 5, wherein: the material of the first object is a material with aluminum as a raw material, and the material of the second object is a material with iron as a raw material.

[0010] The invention of the seventh claim is constituted by the friction stir forming method according to Claim 2, constituted such that: bumps and recesses (7a) are formed in a material of the second object, and the first and second objects are mechanically joined by

pouring the material constituting the first object (6) into those bumps and recesses.

[Effect of the Invention] With Claim 1, a plastic flow is caused by heating and stirring a material constituting a first object (6) in a non-melted state with a friction heat-generating stirring means, and this plastic flow can be used to transfer a convexo-concave state formed on a second object (5) onto the first object (6). Formation is thus possible simply and in a short time, without melting metal materials or requiring extensive skills, in contrast with the fact that it was conventionally only possible to use a method for either melting the first object and pouring it onto the second object, or for mechanically cutting.

[0011] With the invention of the second claim, it is possible to cause a plastic flow by heating and stirring the material constituting the first object (6) in a non-melted state with the friction heat-generating stirring means, and thus to mechanically join the first object (6) with the second object (5). It is thus possible to easily join materials of different types, such as metal and ceramic, aluminum and iron, and so on, which were impossible to join conventionally.

[0012] With the invention of the third claim, it is possible and convenient to join using commonly available milling machines, machine centers, and the like, by using the rotating tool (2).

[0013] With the invention of Claim 4, it is possible to transfer the shape of a forming mold (5a) precisely, which is convenient for parts manufacturing such as for micro machines and the like.

[0014] With the invention of Claim 5, mechanical joining of different types of materials can be done simply.

[0015] With the invention of Claim 6, mechanical joining of aluminum and iron can be done simply.

[0016] With the invention of Claim 7, mechanical joining using bumps and recesses (7a) can be done simply.

[0017] Note that the numbers, etc., in parentheses are for convenience in indicating corresponding elements in drawings, and, accordingly, the present discussion is neither limited nor bound by the content of the drawings.

[0018]

[Mode for Carrying out the Invention] FIG. 1 is a view showing one example of a forming apparatus to which the present invention is applied. FIG. 2 is a view showing changes in mold temperature during formation. FIG. 3 is a view showing the relationship between the depth of a V-groove mold and a filling ratio. FIG. 4 is a view showing a surface state of a mold. FIG. 5 is a view showing a surface state of a tested material before and after using a friction stir forming method. FIG. 6 is a view showing a surface state of a mold. FIG. 7 is a view showing a surface state of a tested material before and after using a friction stir forming method. FIG. 8 is a view

showing the dimensions of a grooved plate. FIG. 9 is a schematic view showing aspects of a tensile shear test and a peel test. FIG. 10 is a view showing a relationship between a maximum load and a distance from a groove center in a tensile shear test and a peel test. FIG. 11 is a view showing a number of grooves and the effects on a maximum load in a tensile shear test. FIG. 12 is an oblique view showing one example of a clad material formed by applying the present invention.

[0019] As shown in FIG. 1, a machining tool 1, acting as a friction stir forming apparatus for performing the friction stir forming method, has a table 3, on which a mold 5 is secured via a securing means such as a bolt nut, not shown in the drawings. A forming mold 5a is formed on a top surface of the mold 5, and the shape on the forming mold 5a is transferred to a workpiece by the material of the workpiece described below becoming a plastic flow according to the forming mold 5a.

[0020] The workpiece 6 to be molded is laminated and secured by an appropriate means, such as a bolt nut, to a portion of the mold 5 to which the forming mold 5a is formed, so as to prevent relative movement with the mold 5, and a rotation-drivable tool 2 is provided above the workpiece 6 in the drawing. The tool 2 is provided to the table 3 so as to be drivably moved in a relative manner to the directions of the arrows A and B which are the vertical directions in the drawing, and to the directions of the arrows C and D which are the horizontal directions, perpendicular to the arrows A and B, by a

feeding mechanism not shown in the drawings. The tool 2 has a cylindrical body 2a.

[0021] A workpiece contact face 2b formed convexly in a slightly downward direction is formed on the lower portion of the body 2a in a direction perpendicular with respect to a tool axis center CL direction, and a probe 2c is formed to a convex center portion of the workpiece contact face 2b in a manner such that the center matches the tool axis center CL, and in a manner protruding downward in the drawing.

[0022] The machine tool 1 having the constitution described above, the friction stir forming performed using the machine tool 1 is described below.

[0023] During machining, the tool 2 is rotated around the axis center CL at a predetermined rotational speed, moved downward in FIG. 1, or in other words in the direction of the arrow B, and the probe 2c on the tool tip is abutted to a top face of the workpiece 6 with a predetermined contact pressure. The workpiece 6 is softened by heating due to friction heat due to the tool 2 abutting in a rotating state, and the probe 2c enters the workpiece 6. Further, as the tool 2 is pressed in the direction of the arrow B, the tool 2 comes into contact with the workpiece contact face 2b and the top face of the workpiece 6 at a predetermined contact pressure, and the top face of the workpiece 6 is further heated by the frictional force created between the workpiece contact face 2b in a rotating state. The

workpiece 6, in a heated state, is stirred by the workpiece contact face 2b in a rotating state of the tool 2 and the probe 2c, thus locally presenting a plastic flow state in a non-melted state. The plastic flow state has significantly lower flow resistance than a plastic flow in ordinary plastic machining, and is a state similar to so-called superplasticity.

[0024] In this state, by rotating the tool 2 and feeding it at a predetermined feeding speed in the direction of the arrow C, the material constituting the workpiece 6 below the tool 2 with a significantly decreased flow resistance is stirred by the tool 2, poured into the forming mold 5a formed in the mold 5, and a protrusion 6c is formed on a bottom face 6b of the workpiece 6 corresponding to the forming mold 5a. At this point, the material constituting the workpiece 6 has extremely high fluidity, and therefore flows from the tool 2 side into the forming mold 5a with a minor force in the direction of the arrow B without requiring great pressure, as in ordinary forging, thus making it possible to transfer the forming mold 5a in an extremely precise manner.

[0025] In this way, by rotating the tool 2 and feeding at a predetermined feeding speed in the direction of the arrow C, the workpiece 6 is continuously heated and stirred, the material constituting the workpiece 6 is poured into the forming mold 5a of the mold 5, and the forming operation is performed continuously.

[0026] Based on the heating due to the friction heat between the tool 2 and the workpiece 6, a flow similar to superplasticity is generated in the material constituting the workpiece 6 with the material in a non-melted state, and poured into the forming mold 5a under a low pressure, thereby making it possible to apply this method to micromachining which has until now been difficult. The inventor offers this as "friction stir forming (hereafter abbreviated FSF)."

[0027] Specifically, the effects of materials, mold shapes, and machining conditions, etc., on microformation of various types of aluminum alloys were experimentally studied using an FSF apparatus created as a prototype using the machine tool 1.

[0028] FIG. 1 shows the FSF apparatus created as a prototype. The apparatus body uses a vertical milling machine and is constituted from the mold 5, the tested material (the workpiece 6), and a fixture securing these. SUS 304 was used as the molding material, and a specular surface, a machined surface, hemisphere grooves, V-shaped grooves, Vicker's and micro-Vicker's impressions were machined on the surface. Further, in order to estimate the temperature during FSF, a K-thermocouple with a diameter of 0.2 mm was buried 1.0 mm below the molded surface. The tool shape used was the TYPE C tool (shoulder face +5°, shoulder diameter 20 mm, material quality SKD61 tempered) given on pages 457-458 of "Ryo NAKURA, Hiroshi INOUE, Spring 2000 Soka Koron (2000)." The tested material (the workpiece 6) used 60 ×

260 × 3 mm A6061P-T6, A2017P-T3, A2024P-T3, and A7075P-T651 aluminum alloys.

<Test Results and Observations>

<Temperature Change during FSF> In order to estimate the temperature during FSF, thermocouples were used to measure the temperature at a total of four points, directly below the V-groove with a cutting depth of 0.5 mm, two 4 mm apart in the center of the tool , and one 8 mm apart on the opposite side. FIG. 2 shows the temperature change 60 mm forward from the forming start point. The test material (the workpiece 6) is A6061P, and a rotation speed of 1320 rpm and a feeding speed of 50 mm/min were used. A maximum temperature of approximately 700 K was found directly below the probe. This was found to drop to approximately 600 K towards the outer circumference of the shoulder.

[0029] <Evaluation of Filling of V-Groove Mold> FIG. 3 shows the results of performing forging using FSF on a 45° V-shaped groove. The rotation speed was 1320 rpm for the A6061P and 530 rpm for the high-tensile aluminum alloy. The feeding speed was 50 mm/min. The same measurement method for the filling ratio was used as in (Yasunori SAOTOME, Seiichi HATA, Koji SAKAGUCHI, "Sosei to Kako, 41-468 (2000), 49-53). The filling ratio tended to decrease as the depth of the mold increased, being highest with A6061P, and decreasing in order with A2017P, A2024P, and A7075P.

[0030] <Evaluation of the Transfer Characteristics> On the basis of the previous section, transfer characteristics were evaluated using the A6061P which had good flow characteristics. First, face-milling was used to make a face in the mold material machined at 170 rpm and a feeding speed of 100 mm/min. The cross-section curve is shown in FIG. 4.

[0031] Using this mold, FSF was performed at 1320 rpm and a feeding speed of 50 mm/min. FIG. 5(a) shows the cross-section curve of the test material (workpiece 6) before the experiment, and FIG. 5(b) shows the cross-section curve directly before the probe after the experiment. Comparing the cross-section curves of the mold and the test material after the experiment, it is clear that the mold shape was transferred favorably, and that Ra and Rz both show similar values.

[0032] FIG. 6 shows the cross-section curve of the mold 5 which has undergone mirror polishing. FSF was performed using this mold in the same way. A test material (the workpiece 6) machined using horizontal milling was used, and the cross-section curve is shown in FIG. 7(a). FIG. 7(b) shows the cross-section curve directly below the probe after the experiment. The mirror face was not transferred, the surface roughness was significantly decreased. This is still to be researched, but it is believed that transfer of the mirror surface is well within the realm of possibility, by improving the tool shape, the machining conditions, and so on.

[0033] <Closed Forging Attempt> The attempt to forge using Vicker's impressions as a mold with A6061P resulted in clear opposing lines of the impressions, confirming that forging was done substantially in line with the mold. Micro-forging using an even smaller mold is thought to be possible.

[0034] Next, an attempt was made to mechanically join an aluminum alloy to a carbon-steel plate by FSF, and the joining strength of the joint was considered.

[0035] <Experiment Method> As shown in FIG. 8 and FIG. 12, a first workpiece 6 for press-fitting was placed over a second workpiece 7 provided with grooves 7a, and these were mechanically joined using FSF in the direction of the arrow C in FIG. 12. The tool used as the TYPE C of "Ryo NAKURA, Hiroshi INOUE, Spring 2000 Soka Koron (2000)," pages 457-458. The workpieces 6 and 7 were a 3-mm-thick A6061P-T6 material (workpiece 6), and S45C material 8 mm on a side (workpiece 7), and the grooves 7a were machined into the S45C as shown in FIG. 8 and FIG. 12. In the experiment, d in FIG. 8 is 1.2 mm, h is 0.2-0.4 mm, and the number of grooves is 1-5.

[0036] The rotation speed of the tool was 1335 rpm, and the joining (feeding) speed was 50 mm/min. A tensile shear test and a peel test were performed using the method shown in FIG. 9 in order to evaluate the strength of the joined joint. The tensile shear test was performed by attaching a steel plate with the same thickness as the A6061P plate (the workpiece 6) on the S45C (the workpiece 7).

<Test Results and Observations>

<One Example of a Clad Material with FSF> FIG. 12 shows an A6061P/S45C clad material, which is an example of mechanical joining using FSF. The aluminum alloy (the workpiece 6) flows into the grooves 7a of the S45C (the workpiece 7) through plastic flow, thus mechanically joining. As a result, favorable joint performance can be expected due to the anchor effect. The cladding ratio in this case is approximately 11%.

[0037] <Strength Evaluation of the Joint> FIG. 10 shows the results of the peel test and the tensile shear test when there is one groove. When h is 0.2 mm, the maximum load falls, but partial separation of the aluminum alloy from the groove was confirmed. A larger h tends to result in a larger maximum load, but the surface area of the aluminum alloy receiving the shear drops as this rises, making it likely that the strength falls.

[0038] Accordingly, h was fixed at 0.3 mm in the experiment, and joints were made with varying numbers of grooves. FIG. 11 shows the results of the tensile shear strength in this case. It was clear that the higher the number of grooves, the greater the maximum load tended to increase. It was found that a greater number of grooves sometimes resulted in breakage from the base material.

[0039] Note that in the above examples, the rotating tool 2 was used as the friction heat-generating stirring means, generating the friction heat in the workpiece 6 which is the first object, but the

rotating tool is not a limitation for the friction heat-generating stirring means. Other aspects are conceivable, such as using reciprocal motion, unidirectional motion in which the outer circumference of a rotating body is pressed against a workpiece, and so on, as long as they can generate friction heat with the first object and stir the material constituting the workpiece whose flow resistance is decreased by the heat.

[0040] Further, the convexo-concave shape formed on the second object transferred to the first object may be any shape formed on the second object surface wished to be transferred to the first object, and is not limited to the forming mold 5a shown in FIG. 1, including, for example, a mirror face.

[Brief Description of the Drawings]

[FIG. 1] FIG. 1 is a view showing one example of a forming apparatus to which the present invention is applied.

[FIG. 2] FIG. 2 is a view showing changes in mold temperature during formation.

[FIG. 3] FIG. 3 is a view showing the relationship between the depth of a V-groove mold and a filling ratio.

[FIG. 4] FIG. 4 is a view showing a surface state of a mold.

[FIG. 5] FIG. 5 is a view showing a surface state of a tested material before and after using a friction stir forming method.

[FIG. 6] FIG. 6 is a view showing a surface state of a mold.

[FIG. 7] FIG. 7 is a view showing a surface state of a tested material before and after using a friction stir forming method.

[FIG. 8] FIG. 8 is a view showing the dimensions of a grooved plate.

[FIG. 9] FIG. 9 is a schematic view showing aspects of a tensile shear test and a peel test.

[FIG. 10] FIG. 10 is a view showing a relationship between a maximum load and a distance from a groove center in a tensile shear test and a peel test.

[FIG. 11] FIG. 11 is a view showing a number of grooves and the effects on a maximum load in a tensile shear test.

[FIG. 12] FIG. 12 is an oblique view showing one example of a clad material formed by applying the present invention.

[Explanation of Reference Numerals]

2 Friction heat-generating stirring means (tool)

5 Second object (mold)

5a Forming mold

6 First object (workpiece)

7 Second object (workpiece)

7a Bumps and recesses (grooves)

Figure 1

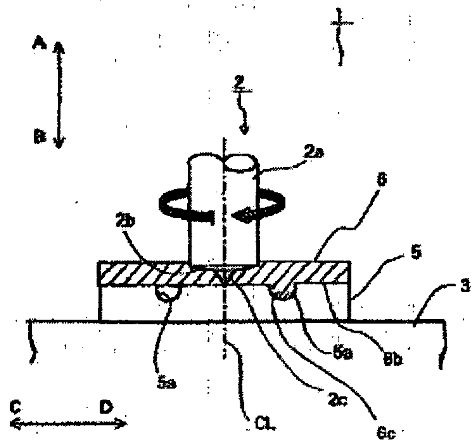
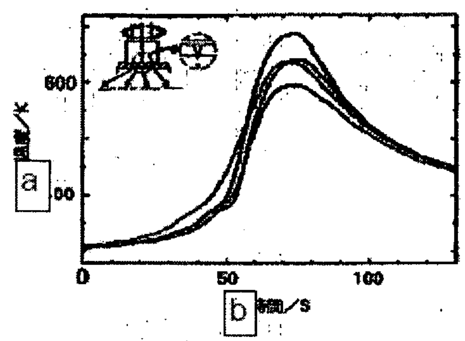
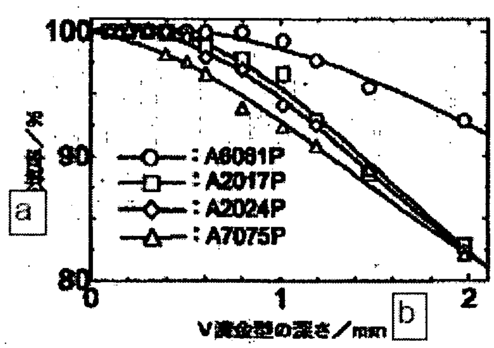


Figure 2



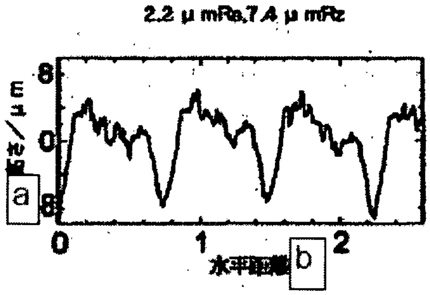
Key: a) Temperature/K; b) Time/S.

Figure 3



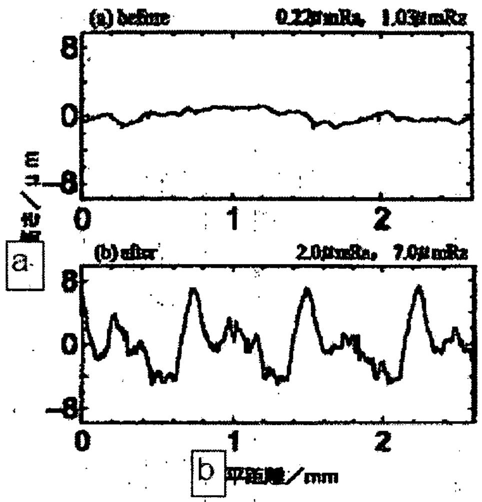
Key: a) Filling factor/%; b) Depth of V-groove die/mm.

Figure 4



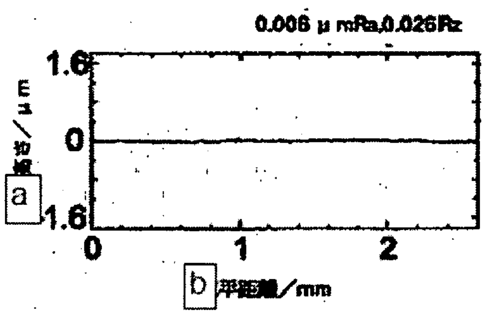
Key: a) Height/μm; b) Horizontal distance.

Figure 5



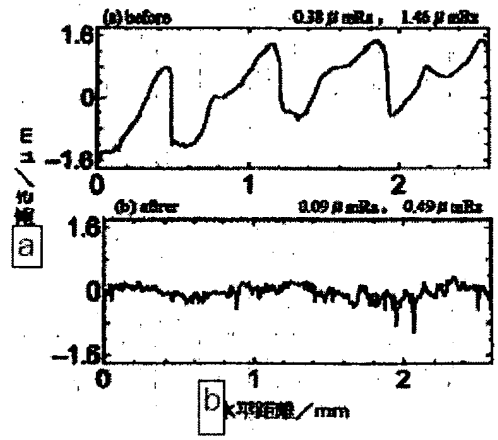
Key: a) Height/μm; b) Horizontal distance.

Figure 6



Key: a) Height/μm; b) Horizontal distance.

Figure 7



Key: a) Height/μm; b) Horizontal distance.

Figure 8

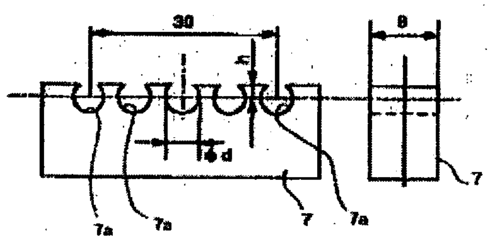
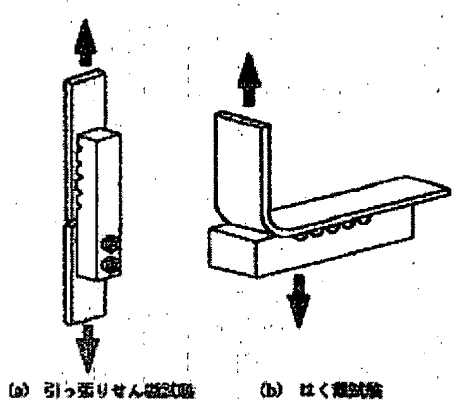
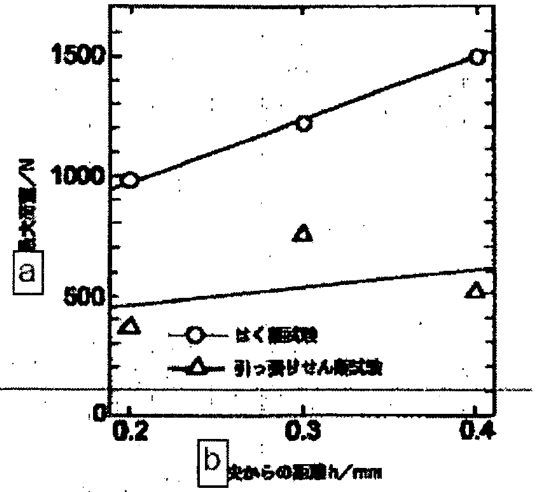


Figure 9



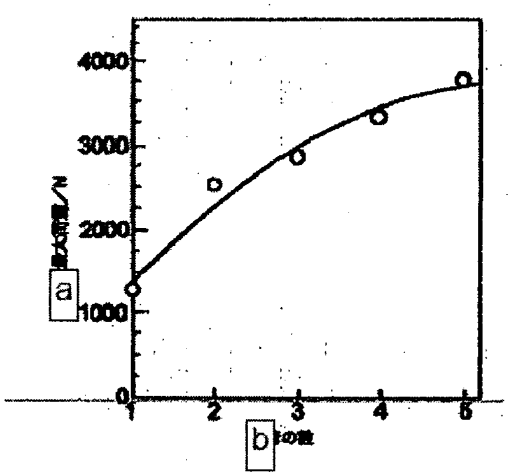
a) Pulling shearing test; b) Adhesion test.

Figure 10



Key: a) Maximum load/N; b) Distance from center h/mm.

Figure 11



Key: a) Maximum load/N; b) Number of grooves.

Figure 12